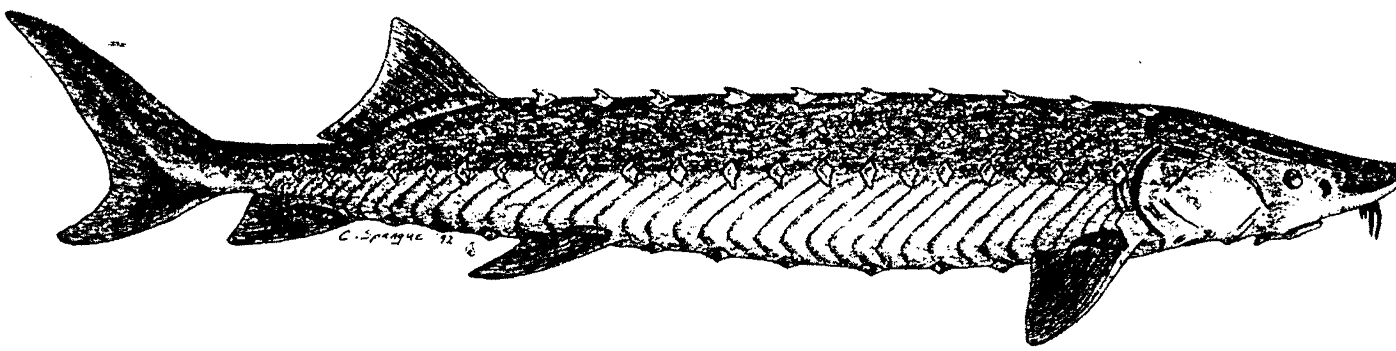
WHITE STURGEON

MANAGEMENT FRAMEWORK PLAN



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data; and (3) the sample size for the Fraser River may be too small to adequately express full genetic diversity.

Brown et al. (1990) suggested that harvest reduces the genetic diversity of the Columbia River's semi-anadromous population. They consider the loss of any genetic diversity in white sturgeon populations as a problem and point out that two-thirds of the sturgeon species in North America are classified as threatened or endangered.

B. DISTRIBUTION AND MOVEMENTS

World Distribution

Historically, white sturgeon may have lived in large rivers and streams from the Aleutian Islands to central California (Scott and Crossman 1973). Individuals may be found as far south as Ensenada, Mexico, but do not represent spawning populations (Moyle 1976; Conte et al. 1988). The distribution of known spawning populations today extends from the Sacramento-San Joaquin rivers to the Fraser River. A more detailed description of the present distribution of white sturgeon is available in Section II of this document.

Historically, most white sturgeon populations had access to the ocean. Some fish spend part of their lives in the ocean. Although white sturgeon may use the marine environment, they do not require access to salt water. Geologic events and the construction of impoundments have isolated several self-sustaining landlocked populations in the Pacific Northwest (Cochnauer et al. 1985; Conte et al. 1988; Brown et al. 1990).

Movement

The following account of white sturgeon movement is probably incomplete and simplistic because most studies cited were not designed to describe movement or distribution. The interpretation of tagging data includes both observation and speculation; most of the authors cited did not clearly indicate which applied. Ongoing projects using sonic and radio tags will increase our knowledge of white sturgeon movement.

Semi-Anadromous Populations

White sturgeon populations in the Sacramento, Columbia, and Fraser rivers use fresh, brackish, and marine waters. At least a portion of these populations use all three habitats and are considered semi-anadromous (see description in Binkowski and Doroshov 1985).

Juveniles rear in fresh or slightly brackish water for an undefined period (Bajkov 1951; Scott and Crossman 1973; Kohlhorst 1976; Kohlhorst et al. 1991). Fraser River sturgeon between 12 in and 40 in (30-100 cm) fork length (FL) move into sloughs when water temperatures reach 56-59° F (13-15° C) in the spring (Lane 1987). Sturgeon move between the backwaters or side channels and the main river in response to tide, light, or temperature (Lane 1987). At some point, at least a portion of the population becomes fully euryhaline and moves into or through marine waters (35 ppt salt). Section I.C. of this document summarizes the available information describing this osmoregulatory transition.

Subadults from semi-anadromous populations commonly use an estuary or river sloughs in the summer. They may move upstream in the fall and early winter to use deep, freshwater areas. During the late winter and early spring, white sturgeon in the Columbia River tend to move downstream, returning to the estuary or ocean (Bajkov 1951). Some individuals may not migrate at all during a particular year (Bajkov 1949). There are subadult white sturgeon in the Sacramento-San Joaquin Estuary year-round, though a few may disperse upstream or downstream (D. Kohlhorst, California Department of Fish and Game, pers. commun.).

In the Columbia River, adults move out of the estuary in fall, migrating either upstream or into marine areas. There are spring and summer migrations into the estuary from upstream and marine areas (Bajkov 1949). White sturgeon migration rates vary. Recent, unpublished radio-tagging studies in the Sacramento River document gravid fish moving upstream at rates of up to 7-10 miles per day (11.3-16.1 km per day; Schaffter 1990).

The proportion of the population that moves into the ocean is unknown. About 1% of the white sturgeon tag recoveries (reward tags) of fish tagged in the Sacramento-San Joaquin Estuary were from distant coastal rivers (Kohlhorst et al. 1991).

The direction white sturgeon travel along the coast varies. Individuals tagged in the Sacramento-San Joaquin Estuary were recovered to the north (Chadwick 1959; Kohlhorst et al. 1991). In contrast, white sturgeon tagged in the Columbia River dispersed north and south of the Columbia River along the Pacific coast and into estuaries of other river systems (Bajkov 1951; Galbreath 1985).

Environmental perturbations in the river may encourage sturgeon to use the marine environment. For instance, Columbia River sturgeon tag returns from the other river systems greatly increased after the 1980 eruption of Mount St. Helens, which deposited millions of tons of sediment in the lower 68 miles (109.4 km) of the river (Galbreath 1985; Boomer and Joner 1989). Reduced abundance of white sturgeon in the Sacramento-San Joaquin system in 1990 and 1991, after several years of drought, may reflect movement of much of the population out of the system (D. Kohlhorst, CDFG, pers. commun.)

Landlocked Populations

Resource managers consider sturgeon confined between dams as discrete populations, even if fish passage facilities are available, because white sturgeon do not readily use fish ladders (Kreitman and LaVoy 1989). However, each year some sturgeon pass through the hydroelectric dams in the Columbia River (Oregon Department of Fish and Wildlife, unpublished data; Donaldson 1958, unpublished manuscript; Appendix Table A2). Tagged sturgeon occasionally move both upstream and downstream through dams (Beamesderfer et al. 1990a; DeVore et al. 1990; D. Weidlein, CDFG, pers. commun.)

Some dams pass more fish than others; in 1989, about 400 sturgeon used the fish ladder at The Dalles Dam while only 60 and 6 sturgeon used the ladders at Bonneville and John Day dams, respectively (J. Weinheimer, Washington Department of Wildlife, pers. commun.). Fish passage facility designs may facilitate salmon passage, but may not be suitable for sturgeon passage. Often the entrance to a ladder is not deep enough in the water column where sturgeon tend to congregate (Donaldson 1958, unpublished manuscript). Upstream and perhaps downstream passage is possible for juveniles, subadults, and adults through some types of fish locks when operated with sturgeon in mind (Donaldson 1958, unpublished manuscript). Downstream passage is possible for juveniles and perhaps subadults via ladders, spillways, and turbines (J. DeVore, Washington Department of Fisheries, pers. commun.). Juvenile sturgeon have been observed in the salmon smolt bypass system at Bonneville Dam (G. McCabe, National Marine Fisheries Service, pers. commun.).

There may be 18 landlocked populations of white sturgeon today. There are about 17 areas, defined by dams, that isolate white sturgeon into populations within the Columbia River system. Hells Gate Dam isolated white sturgeon in the Fraser River system. In California, there was a landlocked population upstream from Shasta Dam on the Sacramento River, but this population no longer exists due to loss of spawning habitat (see Section II.A.).

Within isolated areas, movement patterns of landlocked sturgeon vary relative to fish size. Small landlocked juveniles (about 33-35 in; 85-90 cm) move downstream in summer (Haynes et al. 1978). At least a few juveniles about 39 in (100 cm) long migrate upstream in the late summer and fall (Bajkov 1951). Pronounced seasonal movements by intermediate-sized fish are questionable. Seasonal movement of intermediate-sized sturgeon occurs in the Columbia River; similar movements were not reported by Haynes et al. (1978) for the Hanford Reach of the Columbia River. Larger (about 71 in; 180 cm) individuals move upstream during summer and fall (Haynes et al. 1978). Beamesderfer et al. (1990a) reported wide ranging movements of subadults and adults within lower Columbia River reservoirs during the summer.

Landlocked populations tend to use deep water in the winter and shallow water in the summer, much like semi-anadromous populations (Bajkov 1951; Haynes et al. 1978; Apperson and Anders 1990). In contrast, McCabe (1989) and Parsley et al. (1989) suggested semi-anadromous (in riverine areas) and landlocked juvenile sturgeon do not show a preference for shallow water in the summer.

C. LIFE HISTORY

Sexual Maturity

White sturgeon maturation seems to be determined more by size than age in an aquaculture situation (Conte et al. 1988; S. Doroshov, University of California at Davis, pers. commun.). Males mature as early as 4 years of age in California culture facilities (Conte et al. 1988). Females reared in a hatchery matured at 7-10 years of age (S. Doroshov, UCD, pers. commun.). Both sexes grow much faster in a hatchery than in the wild.

In the wild, the size or age of first maturity is extremely variable. Wild males begin to mature at about 49 in (125 cm) and 26 lb (12 kg) as 12-year-old fish. In the Snake River, some males may mature at 28 in (71 cm) and about 2.4 lb (1 kg; Cochnauer 1981). Females require a longer period to mature, generally 15-32 years. A few fish mature as younger, smaller fish, but an increasing proportion of the population matures as size and age increase (Beamesderfer et al. 1989, 1990a). In the Columbia River, the relationship between the mature proportion of the population and fish size or age is roughly a sigmoid curve (R. Beamesderfer, Oregon Department of Fish and Wildlife, pers. commun.). In the same river, isolated populations that grow slowly, such as the population in Bonneville Pool, seem to mature at smaller sizes and older ages (R. Beamesderfer, ODFW, pers. commun.).

Reproductive Potential

Only a portion of the adult population spawns in any year, but individuals may spawn several times during their lives. Several authors provided rough estimates of spawning frequency of 2-11 years (Stockley 1981; Cochnauer 1983; Doroshov 1985). Preliminary data suggest that the spawning frequency of large females may be as often as every three years (R. Beamesderfer, ODFW, pers. commun.). Male spawning frequency is unknown.

Females

Environmental cues prompting the final stages of gamete development are unknown. Sturgeon raised in captivity develop mature gametes without the water flow (volume) or velocities experienced by wild fish. S. Doroshov (UCD, pers. commun.) indicated that photoperiod and water temperature, in part, prompt the final development of gametes in a culture situation.

In domestic broodstock, initial egg development requires 2-5 years, from the time the gonads are discernable to mature eggs (Binkowski and Doroshov 1985; Conte et al. 1988). Kroll (1990) stated that the previtellogenic stage requires two years, and the vitellogenic phase an additional 1-2 years (a total of 3-4 years). Ripe females carry both mature and immature eggs, but release only the mature eggs. A portion of the remaining immature eggs develop for the next spawning event. Vitellogenesis could begin again immediately after spawning and requires at least 1-2 years. Females may commonly carry 0.1 million to 7 million mature eggs depending upon fish size and age (Bajkov 1949; Scott and Crossman 1973; Stockley 1981; T. Cochnauer, Idaho Department of Fish and Game, pers. commun.; J. DeVore, WDF, pers. commun.). The egg mass may be 7-30% of the mature female's weight (Doroshov 1985; King 1989).

Males

The concentration of sperm is quite variable among mature males (Doroshov 1985). Discussions of variation in sperm concentration with age, time since last spawning, stress, or environment are unavailable. Male spawning may be less dependent upon stimulation from increasing flows (velocity) than female spawning (Schaffter 1990).

Spawning

Throughout their range, white sturgeon spawn between February and July. The earliest spawning, during late winter, occurs at the southern end of their range. Fish spawn later in the spring and into the summer as latitude increases (Appendix Table A3). Most spawning occurs when water temperatures are 50-63° F (10-17° C; range of 9-21° C; Appendix Table A3). D. Lane (Malespina College, pers. commun.) speculates that the optimal water temperature for spawning is 59° F (15° C). Peak spawning in the Sacramento River in 1973 occurred at 58° F (14° C; Kohlhorst 1976).

There is little agreement in the literature concerning the mechanisms influencing spawning frequency. Fish age and size may influence the spawning frequency of females (Scott and Crossman 1973; Beamesderfer et al. 1989). As fish get older and larger, they are more likely to have mature gametes (R. Beamesderfer, ODFW, pers. commun.). In the Fraser River, younger mature fish may spawn every four years, but as they age, individuals spawn less frequently (once every 9-11 years; Scott and Crossman 1973). Additional documentation of declines in spawning frequency with age of female white sturgeon in other rivers is not available because very few older fish are available to sample (R. Beamesderfer, ODFW, pers. commun.).

Descriptions of environmental cues influencing spawning behavior are unavailable. Preliminary data suggest that increased velocity may stimulate females to spawn (Schaffter 1990). Stockley (1981) suggested females may reabsorb their eggs under stress, but does not offer literature citations or data. J. DeVore (WDF, pers. commun.) has noted the reabsorption of eggs after inducement of stress associated with broodstock collection by private aquaculturalists.

Several researchers are evaluating the influence of water velocity and temperature on the spawning behavior of white sturgeon. These efforts are described in Section I.G. of this document.

The relationship between substrate and sturgeon selection of spawning sites is not clear. Spawning areas usually have larger substrate, but whether sturgeon select for substrate, or the substrate type used is an artifact of water velocity, is unclear.

Fertilization and Egg Distribution

In the wild, eggs and sperm are broadcast in fast water. The fast water disperses the adhesive eggs and prevents them from clumping and smothering each other. Optimum velocity information is not available. Limited observations suggest most spawning sites are more than 10 ft (3 m) deep and over cobble substrate (Galbreath 1979; Doroshov 1985; Beckman 1989). United States Fish and Wildlife Service (USFWS) personnel believed they observed natural spawning of white sturgeon in June 1988 (L. Beckman, USFWS, pers. commun.); Parsley et al. (1989) described surfacing and breaching behavior in The Dalles Dam tailrace, believed to be associated with spawning.

The dark gray 0.10-0.16 in (2.5-4 mm) diameter eggs become adhesive in the water and sink (Stockley 1981; Cherr and Clark 1985; Wang et al. 1985). Calcium and magnesium ions in the water enhance the formation of the adhesive jelly and the sperm's acrosome (Cherr and Clark 1985). These ions are also necessary for fertilization and the prevention of cross fertilization with other sturgeon species (Cherr and Clark 1985), although hybridization is unlikely in the wild. Suspended sediment, tannic acid, sodium chloride, or sodium sulfate reduce the adhesiveness of the eggs. A common hatchery practice calls for adding suspended sediment to the eggs to prevent clumping (Doroshov 1985; Conte et al. 1988). Culturists use 5.75 cubic inches dry silt per gallon of water (25 ml dry silt per liter of water; Conte et al. 1988).

As an egg sinks, its asymmetrical density and adhesiveness allow it to adhere to the bottom, micropyle side up. Whether fertilization takes place in the water column or on the stream bottom is unknown. The opportunity for fertilization is relatively high, as each egg has 5-40 micropyle and the sperm remains mobile for 3-5 minutes (Cherr and Clark 1985). In a hatchery, sturgeon eggs can be fertilized for several hours after exposure to water, unlike salmonid eggs (Cherr and Clark 1985). The fertility of ova observed in hatchery sturgeon varies from 3-85% (Monaco and Doroshov 1983).

Eggs remain adhesive for less than three hours (Parsley et al. 1989). If disturbed by changes in flow or other stirring action, they may be dislodged from the bottom (Parsley et al. 1989).

McCabe and Hinton (1990) attempted to describe relationships between egg collections from the water column and environmental factors. Using simple linear regression, they attributed the variation in egg collections to turbidity (73%), dam discharge (54%), temperature (36%), and water velocity (33%).

Incubation

The incubation period is 7-14 days, depending on water temperature (Bajkov 1949; Wang et al. 1985; Conte et al. 1988). Cultured broods tend to hatch synchronously (Conte et al. 1988). Hatching is complete within 20-48 hours (Cech et al. 1984; Doroshov 1985). Most hatching occurs in darkness in the laboratory and may represent adaptive avoidance of visual predators (Brannon et al. 1986). The optimum incubation temperature for subsequent larval viability in a culture situation is 52-63° F (11-17° C; Wang et al. 1987). Higher temperatures of 63-68° F (17-20° C) result in higher mortality and hatching at earlier developmental stages (Wang et al. 1985, 1987). The lower temperature limit for successful incubation is unknown, but may be 43-46° F (6-8° C; Wang et al. 1987). D. Lane (Malespina College, pers. commun.) speculates that water temperature during the spawning and incubation period may limit distribution of the species and influence year-class strength.

In a culture situation, about half of the eggs hatch (Doroshov 1985). There are no similar estimates for hatch rate in the wild. One of the factors potentially influencing egg survival may be the concentrations of toxins in the embryo and yolk (Bosley and Gately 1981; Apperson and Anders 1990).

Larvae

The black 0.4-in (10 mm) larvae are planktonic and drift downstream (Kohlhorst 1976; Stockley 1981; McCabe et al. 1989; Duke et al. 1990). Although larvae have been collected in the field, laboratory experiments provide more complete descriptions of larval development and behavior. The events described below are based on laboratory research. However, Duke et al. (1990) and Miller et al. (1991) described downstream distribution of larvae and young-of-the-year from the spawning grounds.

Under laboratory conditions, Brannon et al. (1986) reported three phases of larval development and behavior between hatching and metamorphosis -- dispersal, hiding, and feeding. At 63° F (17° C), each phase lasts about six days. Larvae still have yolk sacs during the 12-16 days (at 63° F; 17° C) of the dispersal and hiding stages (Brannon et al. 1984; Buddington and Christofferson 1985).

For the first day after hatching (in a laboratory setting), larvae disperse and swim constantly in the water column (Conte et al. 1988). Larvae enter the hiding phase earlier in fast water (0.26 ft/s; 7.9 cm/s) than in slower water (0.07 ft/s; 2.1 cm/s; Brannon et al. 1984). Larvae may control dispersal by entering the hiding phase quickly if water velocities are high (Brannon et al. 1984).

In the absence of current, hiding seems to occur when larvae become negatively phototaxic. Hiding begins as they sink to the bottom and aggregate (Conte et al. 1988). Larvae bury themselves in gravel, sometimes so deep that they cannot escape after yolk sac absorption (Brannon et al. 1984). Cover may be critical for predator avoidance and survival during this second six-day period. The larvae may leave cover if the water temperature changes or dissolved oxygen declines.

At 63° F (17° C), active, or exogenous, feeding begins about 12 days after hatching. The larvae disperse into the water column as they begin to feed (Buddington and Christofferson 1985; Conte et al. 1988) and swim continuously, pausing briefly on the substrate (usually sand) or moving under suspended vegetation (Brannon et al. 1984). Searching for food is the primary activity at this final stage of larval development. When the larvae detect food, they go to the bottom to search (Brannon et al. 1984). Larvae are territorial and will chase other larvae away from food (Brannon et al. 1984; Ruer et al. 1987).

Within 20-30 days after hatching, metamorphosis is complete (Buddington and Christofferson 1985). In culture situations, many larvae do not survive to begin exogenous feeding. They are also susceptible to diseases of the digestive system (see Section I.E.).

Young-of-the-Year, Juveniles, and Subadults

Young-of-the-year sturgeon grow rapidly in a laboratory environment. Their body weight doubles with each 2- to 3-week period (at 61° F; 16° C) during the first four months of life (Brannon et al. 1984). Maximum growth occurs at 68° F (20° C), but rearing at lower temperatures (61-65° F; 16-18° C) minimizes disease (Brannon et al. 1984; Cech et al. 1984; Conte et al. 1988).

The daily food ration needed for wild fish is unknown. To obtain maximum growth, most culture facilities feed young-of-the-year a ration of 20-30% of their body weight daily until they weigh 0.11 oz (3 g; Doroshov et al. 1983). Fish between 0.11 oz and 0.53 oz (3-15 g) receive a ration of about 15% of their body weight per day. Fingerlings over 1 oz (28 g) require only 1.5-2% of their body weight daily (Hung and Lutes 1987; Hung et al. 1989b).

Duke et al. (1990) and Miller et al. (1991) stated that growth during the early years of life (ages 1-4) is greater in the three pools above Bonneville Dam than in the river below the dam.

Food Habits

Sturgeon are opportunistic feeders, using foods that are readily available (Turner and Kelley 1966; Buddington and Christofferson 1985; Buddington and Doroshov 1986a). Diets include mollusks, worms, crustaceans, and fish (Galbreath 1979). Sturgeon also ingest plant material, but scientists feel sturgeon ingest this plant material incidentally (Semakula and Larkin 1968; Cochnauer 1983). Primary components of the diet vary with age, season, and location (Appendix Table A4).

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Larvae have teeth until metamorphosis, which may imply carnivorous feeding habits (Brannon et al. 1984) or a phylogenic connection to carnivorousness (J. DeVore, WDF, pers. commun.). The composition of digestive enzymes in the gut of white sturgeon is also typical of carnivores (Buddington and Doroshov 1986b).

Larvae develop a search "image" at the onset of exogenous feeding (Atema 1977). This image is probably related to the chemical composition of food. Hatcheries use this imprinting phenomenon to wean larvae from live food by using prepared feed containing live food at the onset of feeding (Buddington and Christofferson 1985; Conte et al. 1988). Sturgeon do not seem to imprint strongly on manufactured feed. If initially fed manufactured food, they will still accept live food after 100 days. However, if live food is presented first, then substituted with artificial food, they refuse the artificial food and may starve. Certain live foods, or extracts from them, are readily taken by larvae after the imprinting period. For instance, tubifex worms or the amino acids extracted from tubifex worms attract sturgeon in the laboratory (Brannon et al. 1987).

Benthos or periphyton probably dominate the diet of larval white sturgeon (Brannon et al. 1984), but they may also feed on pelagic fry and zooplankton (Brannon et al. 1984; Buddington and Christofferson 1985). There are no field studies on feeding habits of wild sturgeon larvae.

Young-of-the-year less than 8 in (<20 cm) begin feeding on small (0.039-0.118 in; 1-3 mm) crustaceans (Appendix Table A4). They seek various aquatic insect larvae as they become larger (Bajkov 1949; Galbreath 1979; Cochnauer 1983; Conte et al. 1988). Common foods also include two species of *Corophium* (Appendix Table A4). *Corophium salmonis* was the most important food item for sturgeon <28 in (<72 cm) FL in the lower Columbia River (McCabe and Hinton 1990).

In the laboratory, small sturgeon can capture other sturgeon of similar size or smaller, and are capable of capturing salmonid fry at night (Brannon et al. 1987). Merrell (1961) found that a 54-in (1.37 m) wild white sturgeon that was caught in the Willamette River below Willamette Falls, Oregon, had ingested 14 salmonids ranging from 4-11.5 in (10-29.2 cm) long. Wild sturgeon are known to eat the fry of shad and other species (Appendix Table A4).

Second- and third-year fish (8-24 in; 20-60 cm) feed on tube dwelling amphipods, mysids (*Neomysis* sp.), isopods, other benthic invertebrates, and the eggs or fry of other species of fish (Appendix Table A4).

As sturgeon exceed 24 in (60 cm), their diets become more diverse and commonly include fish (Muir et al. 1988; Appendix Table A4). Seasonal migrations begin to occur in semi-anadromous populations, which may be associated with the abundance of prey (Bajkov 1951; McKechnie and Fenner 1971; Muir et al. 1988). Seasonally abundant foods include eulachon (*Thaleichthys pacificus*), lamprey (*Lampetra* sp.), American shad (*Alosa* *sapidissima*), northern anchovy (*Engraulis mordax*), and herring eggs (Bajkov 1951; McKechnie and Fenner 1971; Doroshov 1985). Eulachon may be the most important food item in winter and spring in the lower Columbia River (Bajkov 1949, 1951). Burrowing Pacific lamprey (*Lampetra tridentatus*) larvae, sculpins, and small striped bass (*Morone saxatilis*) can provide a source of food throughout the year (Appendix Table A4). Other items in the diet include small mollusks (clams, mussels, or snails), crabs, barnacles, isopods, amphipods, polychaetes, nematodes, aquatic insect larvae, and crayfish (Bajkov 1949; McKechnie and Fenner 1971). Lamprey and salmonid carcasses, and moribund juvenile (not necessarily fry) salmonids also provide seasonal foods (Galbreath 1979).

Landlocked sturgeon eat snails, clams, crayfish, amphipods, shrimp, a variety of aquatic insects, worms, fish, and plant material (Cochnauer 1983; Partridge 1983; Duke et al. 1990; Appendix Table A4). Small insects, such as chironomids, sometimes represent the majority of the stomach contents by number or weight (Cochnauer 1983; Partridge 1983).

Although intuitively it seems the distribution of benthic food organisms might influence sturgeon distribution and production, researchers have not been able to correlate benthic invertebrate numbers with sturgeon distribution or growth (Muir et al. 1988; McCabe et al. 1989; Parsley et al. 1989). Sturgeon may compete for food with other fish species. However, little research addresses the potential competition between sturgeon and other species of fish (Muir et al. 1988).

Development of Saltwater Tolerance

The age or size at which wild juvenile white sturgeon normally enter marine or brackish water is unknown (Binkowski and Doroshov 1985). Young-of-the-year (<12 in; <30 cm) and juvenile white sturgeon greater than 12 in (>30 cm) were found in fresh and brackish water (Stevens and Miller 1970; Kohlhorst 1976; McCabe et al. 1989; McCabe and Hinton 1990). Horton (Oregon State University, pers. commun.) reported sturgeon as small as 42 in (107 cm) in the ocean. Tracy (1989b) reported large numbers of fish as small as 18 in (45 cm) FL in brackish estuary waters. Field data correlating salinity with the distribution of various age and size classes of sturgeon are not available.

In the laboratory, young-of-the-year and juvenile white sturgeon are not as tolerant of salt water as larger fish (McEnroe and Cech 1985; Conte et al. 1988). Some mortality of young-of-the-year sturgeon (<0.064 oz; <1.8 g) occurred upon abrupt transfer from fresh water to a salinity of 10 ppt. At 15 ppt, some fry (<0.17 oz; <4.9 g) died. Acclimation of 0.18-oz (5 g) sturgeon to 15 ppt salt water improved their survival at 25 ppt, but they were sluggish (Brannon et al. 1985; McEnroe and Cech 1985). Fish larger than 1.8 oz (>50 g) and about 8.3 in (21 cm) could tolerate half strength sea water (15 ppt; McEnroe and Cech 1985). Although sturgeon survived in 15 ppt salt water, they avoided brackish water (>10 ppt) in preference to fresh water in the laboratory (Brannon et al. 1985).

It is difficult to distinguish between avoidance of salinity and other environmental conditions present in the field. Generally, very small sturgeon use the less saline regions of estuary-river systems. For instance, small sturgeon live in the upper reaches of the Sacramento-San Joaquin River Estuary, such as Suisun Bay, where salinities vary from 0-12 ppt (McEnroe and Cech 1985; CDFG, unpublished data). Muir et al. (1988) reported the Columbia River Estuary is an important feeding area for sturgeon >32 in (>80 cm), while juveniles <24 in (<60 cm) used the less saline regions, upstream from River Mile (RM) 16.8 (Muir et al. 1988).

After becoming euryhaline, sturgeon may pass between salt and fresh water on a seasonal or more frequent basis (Scott and Crossman 1973; McEnroe and Cech 1985). Acclimation to low salinity seemed to improve the survival of small sturgeon in water of slightly higher salinity (McEnroe and Cech 1985). Mechanisms of osmoregulation are unknown, but under study (Doroshov and Cech 1981).

Habitat

Larvae disperse downstream from the incubation area with the river currents. In a semi-anadromous population, some of the larvae reach the upper estuary (Kohlhorst 1976; G. McCabe, NMFS, pers. commun.). The extent of larval dispersal in landlocked populations has not been documented.

Both water velocity and salinity may influence the dispersal of larvae. Brannon et al. (1984) described the relationship between velocity and larvae seeking the river bottom. The distribution and concentration of brackish water probably influence the distribution and survival of larvae and recently metamorphosed fry in the estuary. If larvae disperse and actively select habitats based on velocity, they may move several times a day because of changes in water velocities caused by tides or operations of hydroelectric dams.

Larval sturgeon are found in shallow and deep water (McCabe et al. 1989; McCabe and Hinton 1990). Stockley (1981) found larvae in water 30-65 ft (9-19 m) deep.

The relationships between sturgeon use of areas and the variables of water velocity, temperature, substrate type, and water depth are unclear. The Idaho Department of Fish and Game (IDFG) has an ongoing study that will provide focal point velocity data in the near future. Many of the areas where sturgeon live have sand substrates, but often little else is available. Water temperature preferences seem to occur, but field research on temperature selection has not been conducted.

Depth preference data are difficult to interpret because of the differences in available habitats between management units. Gear type limitations may explain some of the variation, but it is probably not the only factor influencing the reported data. Additional research is necessary to describe the relationship between sturgeon distribution and water depth.

In the lower Columbia River, McCabe and Hinton (1990) collected young-of-the-year (July-October) in water 13-123 ft (4.0-37.5 m) deep. Minimum depths averaged 48 ft (14.7 m) and maximum depths averaged 74 ft (22.6 m).

In a study by Parsley et al. (1989), juvenile sturgeon (8-35 in; 20-90 cm FL) used a wide variety of depths. Juvenile sturgeon were collected in deep water with trawls and in shallow water with gill nets (Parsley et al. 1989). Most (60-85%) of the juvenile sturgeon (about 12-31 in; 30-79 cm FL) were collected in depths from 33-56 ft (10-17 m) with trawl gear in the Bonneville and The Dalles pools in the Columbia River (Parsley et al. 1989; Duke et al. 1990). Trawling was successful 47-75% of the time at other water depths.

Setline data did not demonstrate the same trend in depth distribution for small sturgeon (12-31 in; 30-78 cm). Sturgeon <32 in (<80 cm) caught on setlines were not significantly more abundant, based on catch per unit effort (CPUE), at greater depths in either Bonneville or The Dalles Pool (Beamesderfer et al. 1990a). These authors reported a significant relationship between depth and setline CPUE for sturgeon >32 in (>80 cm). As depth increased up to about 100 ft (30 m), the CPUE increased. It may be inappropriate to describe this observation as a depth preference, since setlines may attract sturgeon from considerable distances.

Coon et al. (1977) found "large numbers" of small sturgeon (18-36 in; 46-91 cm TL) in deep, sandy bottom pools of the upper reaches of the Hells Canyon section of the Snake River. Mid-sized (36-72 in; 91-183 cm TL) and larger sturgeon (>72 in; >183 TL) were more abundant in smaller, more turbulent pools (Coon et al. 1977).

Larger fish may hold or rest in deep water (Bajkov 1951; Haynes et al. 1978; Cochnauer 1983). Although sturgeon commonly use deep pools, they also move into shallow water, perhaps on a daily basis (Haynes et al. 1978). Some researchers do not believe water depth is the habitat variable selected; instead food, water temperature, or light avoidance may prompt movement (Haynes et al. 1978; Stockley 1981).

D. AGE AND GROWTH

White sturgeon live many years. In 1990, the Washington Department of Fisheries (WDF) aged a 53-year-old female downstream from Bonneville Dam (J. DeVore, WDF, pers. commun.) The oldest male aged by Brennan and Cailliet (1989) in California was estimated to be 23 years old. An estimated 102-year-old female was found in the Columbia River (Beamesderfer, ODFW, pers. commun.). Females live about 34-70 years (Brennan and Cailliet 1989). Even the largest males and females aged in recent times do not approach the sizes of sturgeon seen in the late 1800s.

Consistent interpretation of the age of white sturgeon is difficult because of variation in the timing of annuli formation, annuli spacing, and compaction of annuli as the fish get older (Brennan and Cailliet 1989; D. Kohlhorst, CDFG, pers. commun.). Cross sectioning the pectoral fin ray is one of the most reliable aging methods, yet reader agreement is low, especially for fish over 20 years of age (Kohlhorst et al. 1980; Brennan and Cailliet 1989). White sturgeon throughout the region have been injected with oxytetracycline (OTC) to validate the aging technique, with some results pending (Brennan and Cailliet 1991; T. Cochnauer, IDFG, pers. commun.; J. DeVore, WDF, pers. commun.; D. Lane, Malespina College, pers. commun.; T. Nigro, ODFW, pers. commun.). Age validation studies of California and Columbia River wild white sturgeon using OTC indicated that growth patterns in skeletal components are annual and showed distinct OTC markers (Brennan and Cailliet 1991; R. Beamesderfer, ODFW, pers. commun.; J. DeVore, WDF, pers. commun.).

Growth depends upon water temperature and nutrition (Monaco et al. 1981). In the laboratory, a rearing temperature of 64° F (18° C) optimizes growth without compromising survival (Cech et al. 1984; Hung et al. 1989a). Culture facilities use water temperatures between 59° F and 77° F (15-25° C); optimum juvenile growth occurs at 68° F (20° C; Conte et al. 1988).

Growth during the first year is rapid. Larvae are about 0.4 in (1 cm) TL when they hatch. Within the first month, they grow to 1.6 in (4 cm) TL (Galbreath 1985). The fish reach 7-12 in (18-30 cm) TL by the end of the first growing season, based on field observations (Kohlhorst et al. 1980; Duke et al. 1990; McCabe and Hinton 1990). Average length at age varies considerably among white sturgeon populations (see Appendix Table A5).

Sturgeon of the same cohort exhibit variable growth in the field and laboratory (Duke et al. 1990; McCabe and Hinton 1990; K. Ferjancic, Fish Pro, pers. commun.). By their second summer, sturgeon age classes in the Columbia River cannot be identified using length frequency data. For instance, a 12-in (30 cm) fish collected downstream from Bonneville Dam may be age 1, 2, or 3 (Parsley et al. 1989; Duke et al. 1990). Data documenting compensatory growth in white sturgeon populations do not exist. However, compensatory growth mechanisms have been inferred for sturgeon in the Bonneville Pool of the Columbia River. This inference is based on the older age at maturity and average slow growth of individuals in that population.

E. POPULATION

Major factors modifying sturgeon abundance and size distribution include fishing and habitat degradation associated with human population growth. The ability of sturgeon populations to respond to varying levels of exploitation and changing habitats is unknown. Section V of this plan describes the historic influence of exploitation on sturgeon populations. This section examines the range of observed and simulated exploitation rates and theoretical maximum sustained yield.

Structure of a Typical Population

Scientific observations of unharvested white sturgeon populations are not available. Modeling, rather than observation, provides projections of unharvested populations at equilibrium as well as harvest potential (Cochnauer 1983; Debrot et al. 1989; Rieman and Beamesderfer 1990). Population models for white sturgeon, or for any other long-lived species, are very sensitive to small changes in estimated total mortality (Semakula 1963; Ricker 1975; Beamesderfer 1989c; Rieman and Beamesderfer 1990).

Simulations demonstrate that exploitation can have a large effect on the structure of a population of long-lived individuals. The following exercise demonstrates the point without accounting for potential compensatory changes in growth and recruitment as the population changes. An exploitation rate of 0.15 can result in reductions of 54%, 79%, 87%, 92%, and 96% of an age class fished for 5, 10, 13, 16, and 20 years, respectively, at an instantaneous natural mortality rate (M) of 0.075 and a total instantaneous rate of mortality (Z) of 0.23.

Mortality Rates

Annual mortality estimates are not available for sturgeon up to age 5. Some scientists use 0.99 or more as a mortality rate for young-of-the-year, although they acknowledge there are no empirical data to support this rate (Galbreath 1979).

Semakula (1963) and Lukens (1985) estimated the instantaneous natural mortality rate (M) as 0.089 for ages 11-27, and 0.13 for ages 6-25, respectively. Apperson and Anders (1990) provided a much lower natural mortality estimate of 0.03 based on the comparison of two studies. However, they believe this represents an underestimate of natural mortality (K. Apperson, IDFG, pers. commun.).

Estimates of total annual mortality (A) for white sturgeon age 5 and older range from 0.06-0.35 (Semakula 1963; Kohlhorst 1980; Cochnauer 1983; Lukens 1985; Kohlhorst et al. 1991; Appendix Table A6). Kreitman and James (1988) estimated total annual mortality of 0.39-0.44 for a single size class (fish 36-40 in; 91-102 cm) downstream from Bonneville Dam (Columbia River) in 1987.

Estimates of the total instantaneous rate of mortality (Z) for white sturgeon age 5 and older range from 0.06-0.43 (Semakula 1963; Kohlhorst 1980; Cochnauer 1983; Lukens 1985; Kohlhorst et al. 1991; Appendix Table A6).

Estimated rates of exploitation ranged from 0.06-0.35 (Semakula 1963; Kohlhorst 1980; Cochnauer 1983; Lukens 1985; Kreitman and James 1988; Nigro et al. 1988; Kohlhorst et al. 1991; Appendix Table A6). All estimated exploitation rates over 0.15 were from the Columbia River Basin.

Estimated Rates of Sustainable Exploitation

Cochnauer (1983) suggested that the spawning population in the Snake River would gradually decline with exploitation rates of 0.05-0.10 for fish 49-72 in (125-183 cm) long, assuming estimates of total instantaneous mortality rates of 0.06-0.27 from observed data. The middle Snake River population (Hells Canyon) probably experienced exploitation rates of about 0.30 (for fish 10-20 years old) in the mid-1970s (unpublished data collected by Coon et al. 1977 and presented by Lukens 1985).

The Sacramento-San Joaquin Estuary population of sturgeon larger than 40 in (102 cm) TL seemed stable with exploitation rates of 0.06-0.07 (Kohlhorst 1980). Slight population declines might have been due to insufficient recruitment to the minimum legal size (40 in; 102 cm), instead of fishing. Factors limiting recruitment could include a reduced spawning population, poor egg survival, or poor juvenile survival (Kohlhorst 1980). Kohlhorst et al. (1991) reported higher exploitation rates of 0.09-0.12 in the mid-1980s. They suggested these rates are too high to sustain a stable population of white sturgeon in the Sacramento-San Joaquin system.

Semakula (1963) reported an exploitation rate of 0.12 for fish over 36 in (91.5 cm) in the Fraser River downstream from Hells Gate. He stated this is an excessive exploitation rate that removes too many females from the population prior to first spawning, and recommended reducing exploitation to sustain the population. Semakula (1963) also provided an estimate of maximum yield (weight). In the Fraser River system, maximum sustained yield would require postponing harvesting until fish are larger than 36 in (91 cm) and reducing exploitation on this segment of the population to 0.05, or an instantaneous rate of fishing mortality (F) of 0.06. Doubling the recommended fishing mortality increases yield only 22%, exploits smaller fish, and depletes the population.

Rieman and Beamesderfer (1990) modeled white sturgeon populations to determine if Columbia River white sturgeon were being overharvested. They estimated ranges of exploitation rates that provide maximum yields (weight) or will lead to population collapse. Simulations were run for 100 years to represent the population potential of Columbia River sturgeon harvested either with a harvestable size range or without size restrictions. They predicted maximum sustained yields (weight) at exploitation rates of 0.02-0.20 for 36-72 in (92-183 cm) fish for the range of parameters modeled. The assumption of constant recruitment, which suggests substantial compensation, allows the highest exploitation rate. However, if the population exhibits lower compensation, the upper range of modeled exploitation rates may lead to collapse of the population. The authors compared the yields observed in the Columbia River during the late 1800s with the range of predicted sustained yields; they suggested that during 1987 the sturgeon harvest in the Columbia River exceeded by three times any predictable sustainable yield.

Debrot et al. (1989) modeled exploitation rates to examine two issues: (1) the value of a maximum size limit and (2) the sensitivity of their model (H. Schaller, ODFW, pers.

commun.). They estimated that higher rates of exploitation (0.06-0.57) are sustainable with a harvestable size range of 36-72 in (91.5-183 cm) fish than with only a minimum size limit of 36 in (91.5 cm; sustainable exploitation of 0.09-0.25). They estimated that the wide range of exploitation values occurred due to differences in early mortality rates used in the three simulations. They also estimated that it would take 400 years for the population age structure to stabilize under the conditions they modeled.

Disease and Miscellaneous Sources of Mortality

Diseases known to occur in white sturgeon hatcheries include bacterial diseases, protozoans (Costia), fungi, adenovirus, and several poorly understood conditions (Conte et al. 1988). The bacterial diseases caused by *Myxobacter* sp. and *Flexibacter columnaris* occur more frequently at water temperatures approaching 68° F (20° C; Memo from WDF; Conte et al. 1988). Internal *Saprolegnia* fungus and adenovirus affect the digestive tracts of larvae and the fish starve (Conte et al. 1988). An unknown condition inflates the gut with gas, resulting in mortality (Conte et al. 1988). Coccidium, a sporozoan, was identified from a subyearling sturgeon from a California private grower (S. Foott, USFWS, pers. commun.). Also, a herpesvirus has been isolated from hatchery sturgeon at the University of California at Davis (S. Foott, USFWS, pers. commun.).

A horizontally transmitted virus infecting the digestive tract caused mortality in 1984-1986 in California hatcheries (Hedrick et al. 1991). There are no recent reports of this virus.

In 1988, outbreaks of the white sturgeon iridovirus (WSIV), another horizontally transmitted disease affecting the skin and gills, occurred in Oregon and California culture facilities (Hedrick et al. 1991). In 1990, pathologists were able to culture the WSIV (B. Hulbrock, CDFG, pers. commun.). WSIV and reovirus were found in fingerlings raised from Columbia River wild sturgeon gametes collected in 1991 (J. DeVore, WDF, pers. commun.; S. King, ODFW, pers. commun.). The WSIV may have originated in California, however, it is possible the iridovirus is indigenous to the Columbia drainage (T. Kreps, ODFW, pers. commun.).

The influence of parasites and disease on the various life history stages of sturgeon in the wild is poorly known; there are some data documenting parasites of sturgeon. Hoffman (1967) mentions two sturgeon parasites, *Nitzschia quadritestes*, a trematode, and *Cystoopsis acipenseri*, a nematode, which parasitizes white sturgeon (<31 in; <79 cm) in the Columbia River (Duke et al. 1990; McCabe and Hinton 1990). Within a year, one tagged fish infected with *C. acipenseri* had lost the nematode and grown rapidly (Duke et al. 1990). The cestode *Amphilina bipunctata* was described from a sturgeon collected at Dodson, Oregon (Riser 1948). P. Foley (UCD, pers. commun.) has reported two species of parasites on white sturgeon in San Pablo Bay, *Nitzchra quadritestes*, a monogenic trematode found in the buccal cavity and *Salmincola* sp., a copepod.

Predation by other species of fish may be a source of natural mortality for white sturgeon, but estimates of predator-associated mortality are not available.

There are reports of intermittent mortality during maintenance of hydroelectric facilities (J. DeVore, WDF, pers. commun.). For instance, sturgeon entered the draft tubes at Bonneville Dam in November 1981 when the project was temporarily shutdown. Prior to resuming operations, the draft tubes were closed and drained, incidentally killing an estimated 1,000-2,000 sturgeon (J. DeVore, WDF, pers. commun.). Another incident at Bonneville Dam on August 20, 1990, killed an estimated 100-700 white sturgeon in the same manner (J. DeVore, WDF, pers. commun.). The impact of these mortalities on population productivity is unknown.

F. COMMUNITY ECOLOGY

Studies describing sturgeon interactions with other fish species associated with them are not available. There are studies mentioning other fish species as important prey items influencing sturgeon distribution and growth. There were no evaluations identifying potentially competitive species at any life stage.

Other fish species may prey on white sturgeon eggs, larvae, or small juveniles (Beckman 1989). Suckers (Catostomidae), northern squawfish (*Ptychocheilus oregonensis*) and carp (*Cyprinus carpio*) in the Columbia River downstream from McNary Dam have been found with sturgeon eggs in their stomachs. Walleye (*Stizostedion vitreum*) have been found with small sturgeon ($\leq$ 6 in TL) in their stomachs. Some behaviors seem adaptive for predator avoidance, such as spawning during periods of darkness, hatching primarily at night, the larval hiding phase, and avoidance behavior of larvae in the presence of actively feeding predators (Brannon et al. 1986). However, in the wild, ovulation has been observed during daylight (L. Beckman, USFWS, pers. commun.; G. McCabe, USFWS, pers. commun.). Rapid growth may also be a form of predator avoidance (Brannon et al. 1986).

Adult sturgeon are not known to have predators in fresh water except man. Scott and Crossman (1973) stated that Pacific lamprey attack white sturgeon, but documentation is lacking to support this view.

Populations With Access to the Ocean

Although food availability may likely influence white sturgeon abundance and/or behavior, little information is available. McCabe and Hinton (1990) indicated there was no evident relationship between juvenile sturgeon densities and the relative abundance of common foods, primarily invertebrates, in the lower Columbia River. The variable abundance of sardines (*Sardinops sagax*), anchovies (*Engraulis* sp.), smelts, lampreys, and eulachon could influence sturgeon biomass, growth rate, distribution, and maturity rate. Anchovy abundance in the Columbia River Estuary may influence the sturgeon harvest rate during the summer estuary sport fishery (Hess and King 1989). Food availability influences migration patterns.

White sturgeon potentially interact with green sturgeon. The two species co-exist in many estuaries, bays, and nearshore marine areas. Both species spawn in fresh water and spend a portion of their lives in brackish or marine water (Scott and Crossman 1973). However, white sturgeon seem to spend less time in the ocean and use fresh water farther upstream for longer periods in the Columbia River. Populations of green and white sturgeon using the same waterways seem to exhibit some separation in diet. For instance, in the Sacramento and San Joaquin rivers, juvenile green sturgeon ate *Neomysis* and *Corophium* almost exclusively, while white sturgeon had a more diverse diet (Radtke 1966). In the Columbia River Estuary, overlap in diet occurs with seasonally abundant foods such as anchovies (J. DeVore, WDF, pers. commun.). There were no evaluations of potential competition between the species in the ocean.

Populations Without Access to the Ocean

Information relating reservoir aquatic communities to sturgeon production are unavailable. In reservoirs, other fish species potentially compete for food with sturgeon. However, data do not support the theory that landlocked sturgeon populations are food limited. An exception may be the Bonneville Pool (Columbia River) where evidence supports the hypothesis that the population might be food limited.

Other fish species are predators on sturgeon eggs. The configuration of the river and the attractiveness of tailrace areas to some of these predator species may congregate them in areas where sturgeon spawn.

G. HABITAT CONCERNS

Data are insufficient to adequately describe the relationship between sturgeon production and habitat parameters, and the mechanisms controlling these relationships. Despite the scarcity of information, the degradation of sturgeon habitat from water pollution and habitat changes has been attributed to human activities. Impoundments and water diversions created barriers, changed flow regimes, and modified access to food.

Flows

Recent research has focused on the relationship between flows during the spring spawning period and sturgeon production in both the Sacramento-San Joaquin River Estuary and the Columbia River Basin.

Abundance of a year class appears positively associated with the volume of freshwater flow through the Sacramento-San Joaquin Estuary (Kohlhorst et al. 1991). The mechanism that influences this remains unknown. Increased flow may increase egg deposition by stimulating spawning or may increase survival of young-of-the-year. Perhaps increased flow moves larvae and juveniles into a rich estuarine environment earlier or the additional freshwater flow may decrease the salinity in the estuary and increase the survival of very small sturgeon (see Section I.C.). In the mainstem Columbia River, reproduction has been greater during years of higher flow versus years of lower flow. Spawning also occurs earlier and at lower temperatures during high flow years than low flow years (L. Beckman, USFWS, pers. commun.).

Tracy (1988, 1989b, 1990) described a relationship among the date of sturgeon spawning, flows, and water temperature. The date of spawning was estimated by collecting eggs or larvae, aging them using information from aquaculture research, and back-calculating using river water temperature. Spawning was greatest when flows were >150,000 cubic feet per second (cfs) and temperatures were between 50° F and 63° F (10-17° C). Tracy (1990) compared his work to data presented in Parsley et al. (1989) and concluded that minimum daily flow or stability of flow rather than mean daily flow may influence spawning activity. Tracy (1990) further concluded that for the region downstream from Bonneville Dam "there was a correlation between minimum preferred flows and spawning activity, and no apparent correlation between spawning activity and daily range of flow." However, this may be due to the constant high flows below the dam, which may be above some threshold flow level affecting spawning.

Use of Impoundments

A better understanding of the ecological relationships influencing landlocked populations in each impoundment is needed. It may be valuable to critically examine the difference between habitats in regions where white sturgeon are abundant and those regions where they no longer exist.

Contaminants

The influence of water pollution on sturgeon populations is not well understood. Toxins such as polychlorinated biphenyls (PCBs), mercury, selenium, and dioxins have been found in sturgeon tissues (Kohlhorst 1980; CDFG, unpublished data; IDFG, unpublished data). Doroshov (1990) stated that white sturgeon tend to accumulate toxins in egg tissue, and these toxins could reduce reproductive potential. As little as 4.1 micrograms per lb (9 micrograms/kg; micrograms per kg=parts per billion) of copper can inhibit the ability of larvae to absorb their yolk (Apperson and Anders 1990 citing unpublished work by Van Eenennaam at UCD).

Observed concentrations of organochlorides in white sturgeon vary. Bosley and Gately (1981) described DDT (dichloro diphenyl trichloroethane), DDE (dichloro-diphenyl-ethylene), and DDD (dichloro diphenyl dichloroethane) concentrations as high as 31.7 parts per million (ppm) in sturgeon liver samples collected in McNary Pool (Columbia River).

The eggs and hatchery-reared larvae of Kootenai River (Idaho) sturgeon contained organochloride (DDD, DDE, dieldron, endosulfante, and methosychlor) concentrations of 0.04-0.08 ppm (IDFG, unpublished data).

Kohlhorst (1980) reported high PCB concentrations in gonad and muscle tissue of white sturgeon collected in 1974. More recent data did not confirm these high levels (D. Kohlhorst, CDFG, pers. commun.). The mean PCB levels in white sturgeon flesh (22 ppm) and gonad (24-49 ppm) samples collected in 1974 were higher than the mean PCB levels reported for flesh (0.1-0.8 ppm) and gonads (0.7-8.9 ppm) collected between 1982 and 1984 (D. Kohlhorst, CDFG, unpublished data). PCB concentrations were occasionally as high as 1.9 ppm in some of the sturgeon in McNary Pool of the Columbia River (Bosley and Gately 1981).

Dioxin research is under way in several Columbia River locations. Beak Consultants examined dioxin levels in Columbia River sturgeon; the results are pending. The Washington Department of Ecology (WDE) found relatively high dioxin levels (0.117-0.222 ppb) in the edible tissue of two of the three white sturgeon sampled in Lake Roosevelt (Memorandum to Carl Neuchterlein, WDE, from Art Johnson and others dated November 5, 1990). The Environmental Protection Agency (EPA) has planned a Columbia River Basin dioxin study (B. Kleland, EPA, pers. commun.). Some of the dioxins may originate from pulp mill discharge. Dioxins are present in upper Sacramento River fish, leading to health warnings for the human consumption of rainbow trout (*Oncorhynchus mykiss*). Analyses for dioxins have not been performed on sturgeon from the Sacramento-San Joaquin Estuary (D. Kohlhorst, CDFG, pers. commun.).

Dauble and Price (1990) reported low radionuclide concentrations in liver, muscle, and cartilage tissue of sturgeon collected in the Columbia River from Lake Roosevelt to Astoria, Oregon. These radionuclide burdens are below the standards for human radiation dosage.

Mercury levels in flesh samples of Sacramento-San Joaquin River white sturgeon collected in 1981 and 1983 were about 0.24 ppm and 0.26 ppm wet weight, respectively (D. Kohlhorst, CDFG, unpublished data).

Mean selenium levels found in white sturgeon flesh from the Sacramento-San Joaquin Estuary in 1986, 1987, and 1988 ranged from 1.48-2.32 ppm wet weight (D. Kohlhorst, CDFG, unpublished data).

In Idaho, high concentrations of dissolved copper and zinc and high sediment loads potentially limit reproduction of Kootenai River sturgeon (K. Apperson, IDFG, pers. commun.). Egg tissues sampled from Kootenai River sturgeon contained 0.7-1.6 ppm copper, 3.3-17.8 ppm zinc, 4.6-24.0 ppm aluminum, and 0.1-0.5 ppm lead (IDFG, unpublished data).

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II. DISTRIBUTION, ABUNDANCE, AND HABITAT USE BY MANAGEMENT UNIT

Management units are defined by the location of river basins and the location of barriers to sturgeon passage. This section provides a brief orientation to each management unit and the distribution of sturgeon within the management unit. This section also attempts to provide an indication of population status, based on abundance estimates or production indices.

A. SACRAMENTO AND SAN JOAQUIN RIVERS

Habitat Available

The Sacramento-San Joaquin River Basin contains a reproducing population of white sturgeon that spawns primarily in the Sacramento River, sometimes as far upstream as Shasta Dam (Kohlhorst et al. 1991). Some sturgeon also spawn in the San Joaquin River upstream to the confluence with the Merced River. A remnant population was trapped above Shasta Dam when it was completed in 1944 and reproduced successfully, probably until the early 1960s (Fisk 1963). There are no recent records of white sturgeon in Shasta Lake.

The Sacramento-San Joaquin River Basin drains about 59,000 square miles (153,000 sq km) in California's Central Valley (Figures 1, 2). The Central Valley is a rich, arid agricultural area irrigated partly with water from these two rivers. The Sacramento River is the larger of the two rivers, contributing about 85% of the 28 million acre-feet of historical annual discharge in the basin (Nichols et al. 1986).

Irrigation and municipal uses divert over 60% of the Sacramento and San Joaquin rivers' annual discharge. Public water projects dominate water development in the basin (U.S. Bureau of Reclamation's Central Valley Project and California's State Water Project). Nearly 40% of the historic (1850) flow of the Sacramento-San Joaquin River system is removed for local agricultural and municipal consumption upstream and within the delta. Another 24% is exported from the delta for agricultural and municipal use in central and southern California (Nichols et al. 1986). Water storage projects altered the seasonal distribution of flows, decreasing winter flows and increasing summer flows in the rivers upstream from the delta.

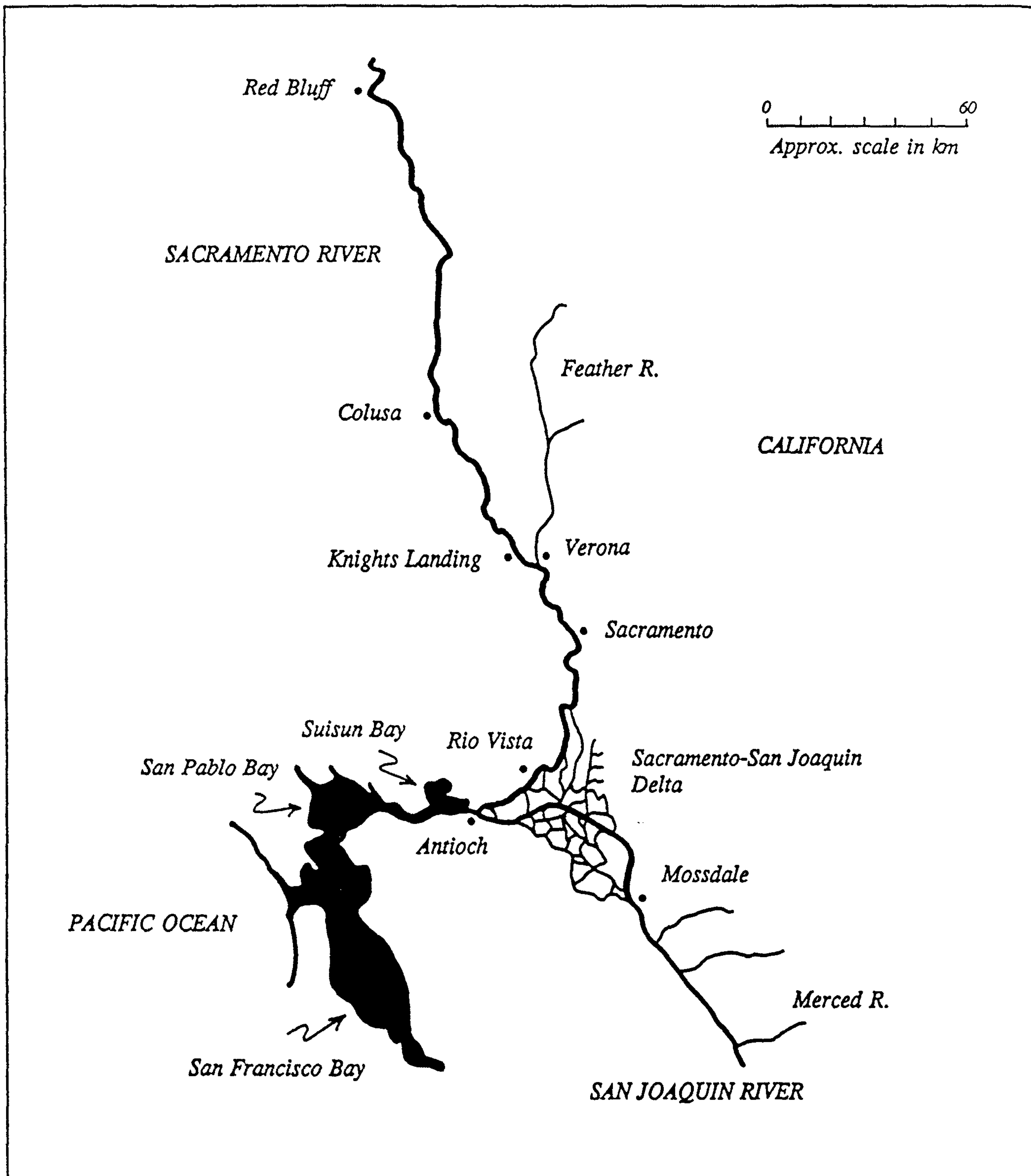

Figure 1. Map of the Sacramento-San Joaquin River Basin from the Pacific Ocean upstream to the community of Red Bluff on the Sacramento River and upstream along the San Joaquin River to one of its tributaries, the Merced River.

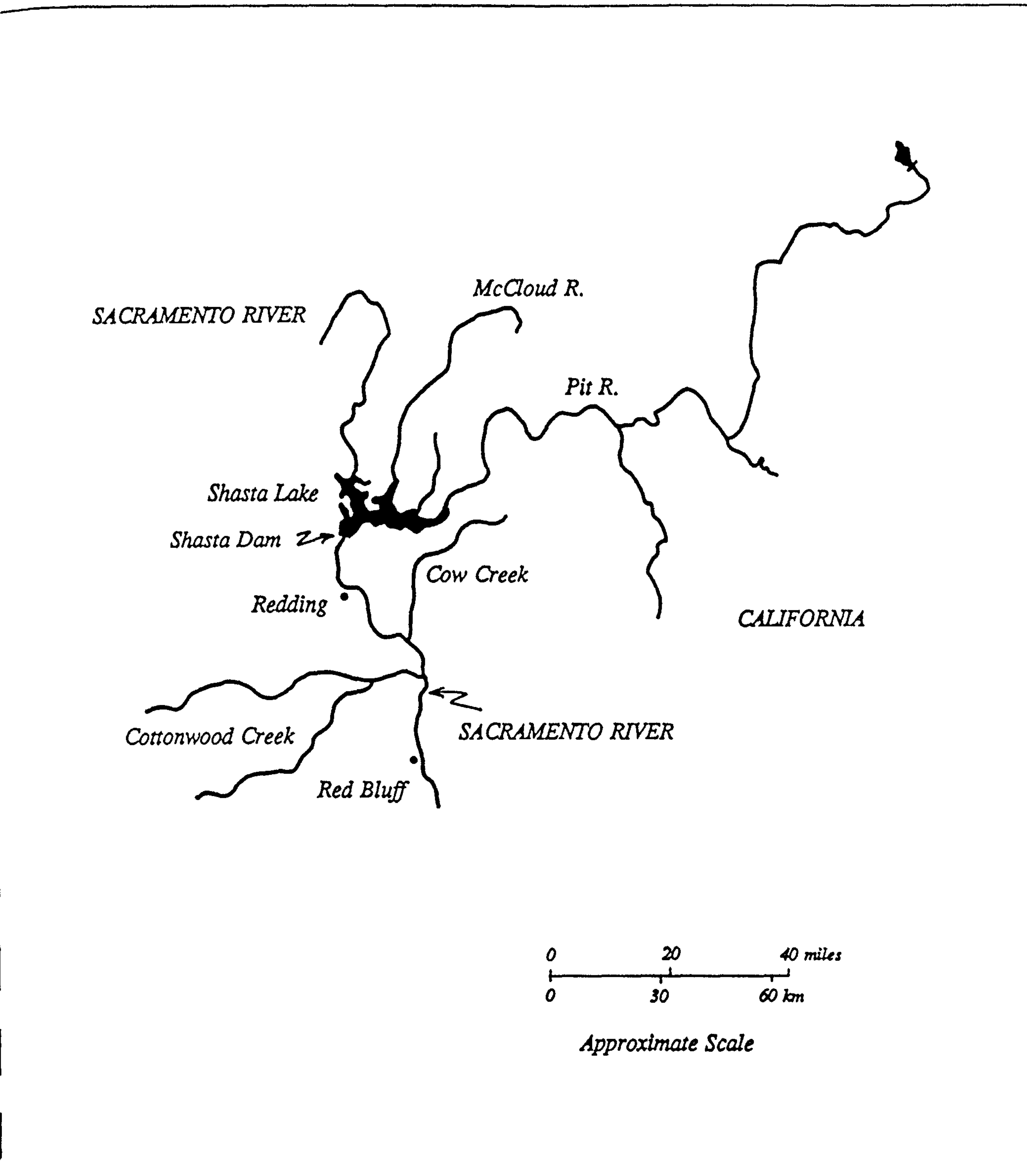

Figure 2. Map of the upper Sacramento River Basin from the community of Red Bluff upstream to its headwaters.

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The confluence of the Sacramento and San Joaquin rivers forms a large, complex tidal estuary. Most of the land in the delta is below sea level and protected by levees built during the late 1800s and early 1900s. An intricate network of over 683 miles (1,100 km) of tidal channels weave through these lands before draining into the first of the three bays in the estuary. These channels are a maximum of 50 ft (15 m) deep and between 160 ft and 0.9 miles (0.05-1.5 km) wide. Suisun and San Pablo bays are primarily shallow flats with associated marshes. In the past, these marshes flooded seasonally (Schulz and Simons 1972). The third bay is San Francisco Bay, a deepwater bay.

Distribution and Habitat Use

Large adult sturgeon use San Francisco, San Pablo, and Suisun bays and the Sacramento-San Joaquin Delta (Figure 1). White sturgeon inhabit the estuary year-round (Miller 1972a). Flows and salinity influence their distribution in the estuary. The center of their distribution is farther upstream in low-flow years when salinity increases, and farther downstream in high-flow years when salinity declines. Tagging studies indicate that mature adults move upriver to spawn in early spring (Miller 1972a; Kohlhorst et al. 1991).

White sturgeon may migrate over 200 miles (330 km) up the Sacramento River to spawn, based on the distribution of possible spawning habitat, the observation of large fish, and larval collections (Stevens and Miller 1970; Miller 1972a; Kohlhorst 1976; Kohlhorst et al. 1991). The Feather River, a tributary to the Sacramento River, may provide spawning habitat for white sturgeon (Miller 1972a). Spawning also occurs in the San Joaquin River, based on catches of adult fish there in the late winter and early spring (Kohlhorst et al. 1991).

Larvae are dispersed throughout the Sacramento River and Sacramento-San Joaquin Delta. Sturgeon larvae and eggs were found in the Sacramento River near the community of Colusa (RM 145), at RM 112, Knights Landing, and near the confluence of the Feather River (Stevens and Miller 1970; Kohlhorst 1976). Larvae and young-of-the-year (0.8-2.4 in; 2-6 cm) were found in the lower delta between Collinsville and Rio Vista, and at the junction of Georgiana Slough and the North Fork Mokelumne River (Turner and Kelley 1966; Stevens and Miller 1970). More larvae are found in the delta and Suisun Bay in years with high river flow (Kohlhorst 1976). Young-of-the-year (8 in; 20 cm TL) and fish <16 in (<40 cm) TL use the delta year-round (Radtke 1966; Stevens and Miller 1970); 60% of these were found in the lower Sacramento River (Radtke 1966).

White sturgeon tag returns from the San Joaquin River suggest the river supports only 10% of the spawning population in the basin (Kohlhorst et al. 1991). One male sturgeon was caught near Mossdale in the San Joaquin River in the mid-1960s (Radtke 1966). Anglers catch sturgeon in the San Joaquin River in late winter and early spring (presumably a spawning run) from Mossdale upstream to the confluence of the Merced River (Kohlhorst 1976). The San Joaquin River may have been a more important spawning area prior to its

degradation by man (Miller 1972a). The San Joaquin River
reductions due to water development and by pollution from a,

Juvenile white sturgeon use different areas of the basin juveniles are found in the Sacramento River and in other parts Delta. As juvenile sturgeon grow, they move closer to the oce downstream bays (Suisun, San Pablo, and San Francisco bays). Sacramento-San Joaquin Delta are smaller than those found in S Larger juveniles, primarily 20-28 in (51-71 cm) long (range 12- use San Pablo and Suisun bays (Radtke 1966).

White sturgeon probably used the Sacramento River upstr the construction of Shasta Dam in 1944 (Figure 2). Sturgeon we... in Shasta Lake in the early 1960s (Fisk 1963) and used the Pit River prior to the construction of Shasta Dam and for many years afterward (Wales 1945; Fisk 1963). The last report of white sturgeon in either the Pit River or Shasta Lake was in 1973 (T. Healey, CDFG, pers. commun.). Sturgeon are no longer found in the Pit River (D. Weidlein, CDFG, pers. commun.). At least three changes in habitat could have eliminated reproduction of sturgeon above Shasta Dam:

1) The recent construction of additional impoundments in the downstream reaches of the Pit River blocked passage.

2) Any potential spawning habitat remaining was flooded by Shasta Lake.

3) The diversion of cold water from the McCloud River into the Pit River reduced the temperature of the Pit River.

Abundance, Status, and Productivity

White sturgeon (>40 in; 102 cm) population estimates for the Sacramento-San Joaquin Delta have fluctuated between 11,000 and 128,000 fish during the past 37 years (Kohlhorst et al. 1991; Figure 3). Although the estimates have wide confidence intervals, the point estimates exhibit a trend similar to catch-per-unit-effort (CPUE) trends (Kohlhorst et al. 1991). The population is declining from the record high estimate of 1984 (Kohlhorst et al. 1991).

Sacramento-San Joaquin Estuary white sturgeon grow faster than other West Coast populations up to about age 12 and more slowly than other populations thereafter (Kohlhorst et al. 1980; Appendix Table A5).

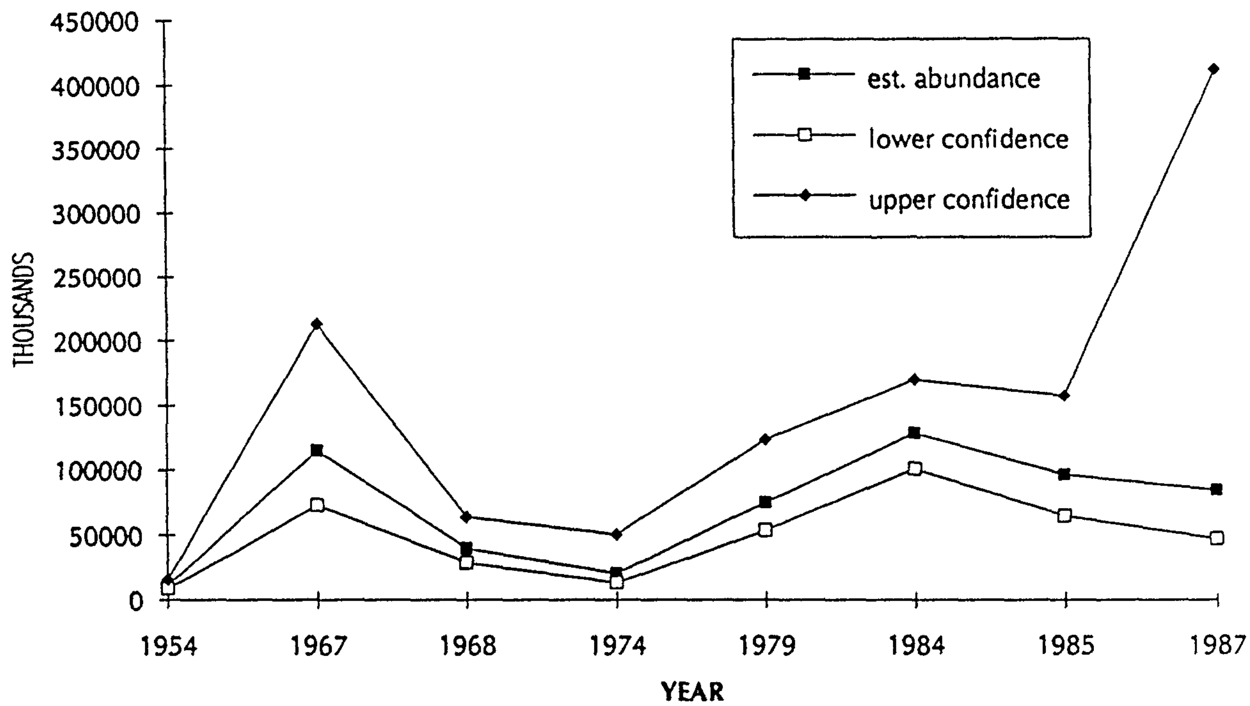

Figure 3. Estimated relative abundance of white sturgeon >40 in (>102 cm) TL in the Sacramento-San Joaquin River system over time (miscellaneous years between 1953 and 1990), based on population estimates within San Pablo Bay (adapted from Kohlhorst et al. 1991).

B. COLUMBIA RIVER DOWNSTREAM FROM BONNEVILLE DAM

Habitat Available

The tide influences water surface elevation and water velocity of the .. River for 145 miles (233 km) up to Bonneville Dam (Figure 4). The lower 46 miles ... of the river are considered to be the estuary (Fox et al. 1984). The estuary is a "drowned river valley," characterized by changing salinity regimes (Fox et al. 1984). The lower estuary (up to RM 30) can be brackish or marine depending upon river flow, tidal stage, and depth, while the remainder is strictly fresh water. The estuary was described by Fox et al. (1984):

> The Columbia River Estuary is characterized by a complex series of channels, tidal flats, and submerged sandbars and is surrounded by shallow peripheral bays. The channels seldom exceed 18 m in depth and the tidal flats are exposed at low tide. The most prominent features of the bathymetry are the division of the main estuarine channel into the main navigation and north channels just upriver from the entrance, the tidal sandflats between RM 10 and 25, and the numerous channels and tidal-marsh islands in Cathlamet Bay. These numerous features are a major factor affecting the estuary's water circulation patterns.

Salinity in the estuary varies with tidal stage, river flow, and distance from the mouth (Neal 1972; Fox et al. 1984). During high river flow and low tides, the estuary is entirely fresh water. During low river flow, the minimum intrusion of saline water at a depth of 29.5 ft (9 m) is 11-13 miles (18-21 km). Maximum salinity intrusion is about 30 miles (48 km) upstream from the mouth and occurs at low flows and depths of 29.5 ft (9 m) or greater. Maximum salinity intrusion occurs in late summer and fall (Fox et al. 1984).

The river upstream from the estuary is not very diverse. Islands create some habitat diversity in this portion of the river. The substrate is primarily sand. There are approximately 6-7 miles (9.7-11.3 km) of cobble/boulder substrate immediately downstream from Bonneville Dam.

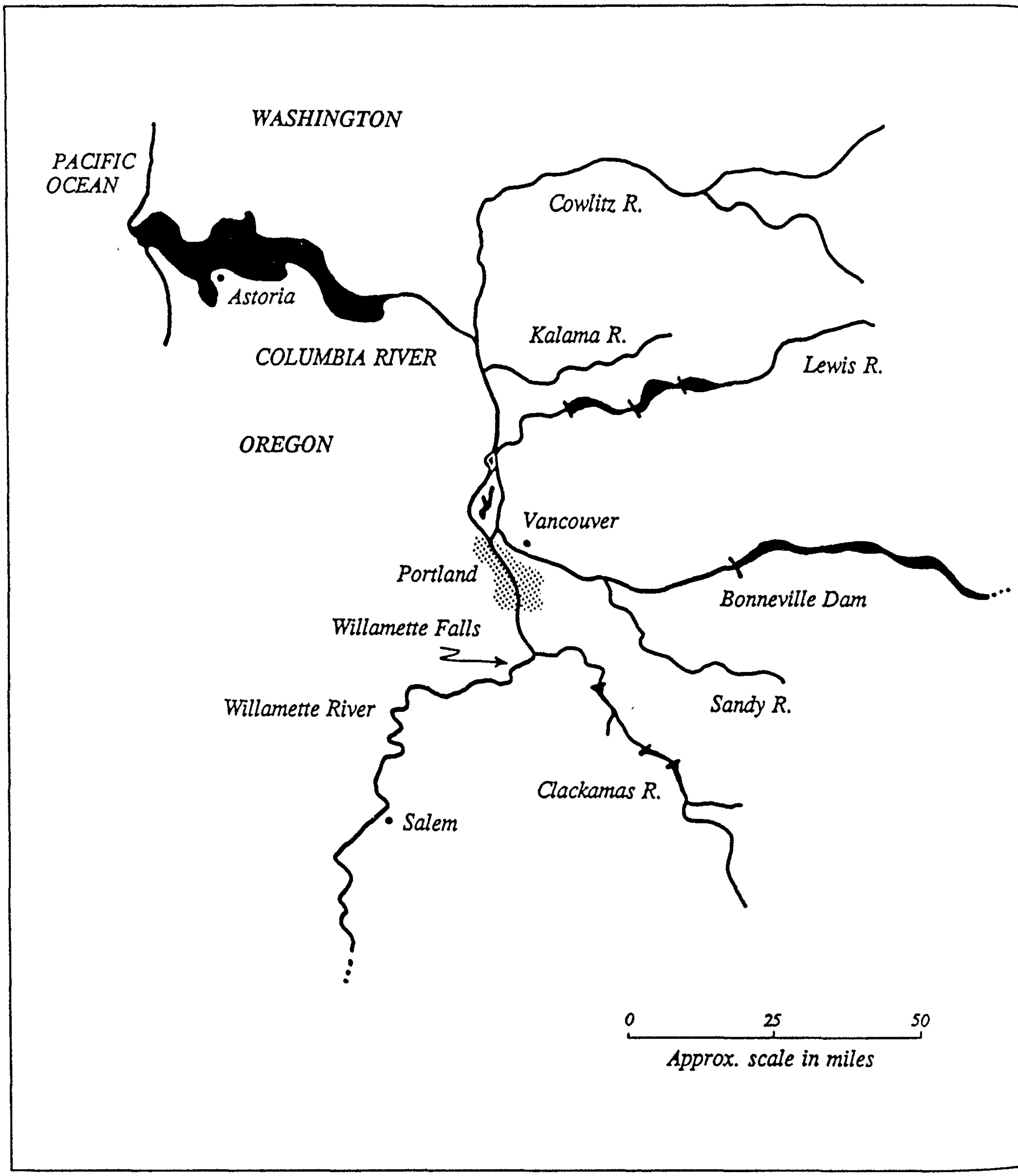

Figure 4. Map of the Columbia River and selected tributaries from the Pacific Ocean upstream to Bonneville Dam and one of its tributaries, the Willamette River.

Distribution and Habitat Use

White sturgeon are found throughout the 145 miles (233 km) of the Columbia River downstream from Bonneville Dam. White sturgeon also use the Willamette River up to Willamette Falls, which blocks upriver migration (Bennett 1988; Al Smith, ODFW, Intra-departmental memo, August 11, 1989). Prior to basin development, Willamette Falls was inundated during flood stage and sturgeon may have passed upstream (R. Beamesderfer, ODFW, pers. commun.). The Oregon Department of Fish and Wildlife (ODFW) planted white sturgeon upstream from Willamette Falls in 1950-1951 and 1989-1991. White sturgeon also use the lower Grays and Deep rivers. Juvenile fish make extensive use of these tributaries, which are tidally influenced; adults were also seen in these rivers.

Sport harvest records indicate white sturgeon use the Cowlitz River upstream to RM 50, where there is a barrier at the Cowlitz River Salmon Hatchery (Stockley 1981; J. DeVore, WDF, pers. commun.). Interestingly, white sturgeon were not observed in the Cowlitz River prior to the eruption of Mount St. Helens. The distribution of sturgeon in other lower Columbia tributaries, such as the Clatskanie, Kalama, Washougal, Lewis, and Sandy rivers, has not been documented.

White sturgeon spawn primarily just downstream from Bonneville Dam. The area has swift waters and cobble/boulder substrate typical of the literature's description of sturgeon spawning areas. This spawning habitat was identified via observation of large adults and collections of recently fertilized eggs in the vicinity. Eggs were found on artificial substrates placed just downstream from the Bonneville Dam spillway (McCabe et al. 1989) and were also collected as far downstream as RM 139, or within six miles (9.7 km) of the dam. Spawning may occur throughout the 6-mile (9.7 km) reach (McCabe and Hinton 1990). The river bottom is primarily cobble/boulder for 6-7 miles (9.7-11.3 km) downstream from the dam (McCabe et al. 1989). Although the channel appears confined, the topography of the river bottom is variable.

Larval sturgeon can be found throughout the lower river (G. McCabe, NMFS, pers. commun.). Larvae disperse throughout the river with the current, based on sampling with stationary plankton nets (G. McCabe, NMFS, pers. commun.). More larvae can be found within 30 miles (48 km) of the dam than in other areas (LaVoy 1989; McCabe and Hinton 1990). In 1990, a few larvae were found as far downstream as the estuary (G. McCabe, NMFS, pers. commun.). In most of the areas where larvae are found, the river channel is relatively confined and swift, with primarily a sand substrate.

Post-larval young-of-the-year sturgeon were most abundant between the Willamette River confluence (RM 101) and the estuary (RM 31; McCabe and Hinton 1990). McCabe and Hinton (1990) collected relatively few (111) post-larval young-of-the-year, making habitat preferences difficult to establish. These young fish used water between 49 ft and 76 ft (15-23 m; mean minimum at maximum depths) deep with sand substrate (McCabe and Hinton 1990). This was their distribution during daylight hours; very little sampling was done during hours of darkness. Since young sturgeon are photophobic (Beer 1980; Levin 1982), testing for diurnal/nocturnal differences in depth distribution may be helpful.

Juvenile sturgeon 12-24 in (30-61 cm) FL and at least 1-year-old dominated the semi-balloon trawl samples of McCabe and Hinton (1990). High catches of juveniles occurred at RM 95 and RM 131, although sampling was not randomly distributed throughout the lower river. The highest catches of juvenile sturgeon occurred in water 60 ft deep (18.3 m) or greater (McCabe and Hinton 1990). Small sturgeon also used water 30-59 ft (9.1-18.2 m) deep; fewer were found in waters <30 ft (<9.1 m) deep (McCabe and Hinton 1990). Similar observations were found in impounded areas (Duke et al. 1990).

Subadult juveniles >28 in (>71 cm) FL and adult sturgeon use the entire 145 miles (233 km) of the lower Columbia River, migrating freely within this section (Bajkov 1949, 1951; Hess and King 1989).

Sturgeon in the Columbia River downstream from Bonneville Dam may use the ocean for a portion of their lives. See Section I.C. for a discussion of salt tolerance.

Abundance, Status, and Productivity

The sturgeon population in the Columbia River downstream from Bonneville Dam is considered to be a discrete population. The population is semi-anadromous, and therefore not a closed population, which confounds population estimation procedures. Modelers trying to estimate abundance have therefore stratified mark and recovery data to estimate abundance at times when migrations into and out of the Columbia River are at low levels. At these times, mixing of tagged and untagged fish would reduce biases associated with open system assessment. These abundance estimates can be considered underestimates due to the lack of sampling of Columbia River white sturgeon in marine areas. Also, there is exploitation in the ocean from the nearshore groundfish trawl fishery. Population interchange between the marine and riverine emigrants potentially introduces another source of unquantifiable bias in the population estimates based on a mark-recapture tagging program.

Kreitman and LaVoy (1989) estimated the inriver population size of 36-72 in (91-183 cm) TL white sturgeon downstream from Bonneville Dam to be approximately 150,000-300,000 fish in 1987. Subsequent refinement of the 1987 data indicated that the abundance of 36-72 in (91-183 cm) white sturgeon in the lower Columbia River was about 238,700 fish (DeVore et al., in press).

Abundance estimation was problematic for the 1988 tag group due to an abnormally low recovery of marks that year. Estimates of abundance for the 1989 tag group indicate that approximately 217,400 white sturgeon between 36 in and 72 in (91-183 cm) TL inhabited the lower Columbia River in that year (DeVore et al., in press).

Since mark-recovery strategies for the lower Columbia River modeling effort depend on sampling fisheries operating under the 6-ft (1.8 m) maximum size limit, abundance estimates of broodstock are not available. Indices of broodstock abundance are available and indicate this segment of the population remains healthy. Melcher and King (1991) reported a stable trend in the handling rate of oversized white sturgeon in lower Columbia recreational fisheries for the past seven years. Also, there is continued strong recruitment of young sturgeon into the sport fishery.

The growth rate of white sturgeon in the lower Columbia River is intermediate between rates observed in the Sacramento and Fraser rivers. The average fish in the lower Columbia River reaches a TL of 36 in (91 cm) by age 9, while fish from the Sacramento and Fraser rivers reach 36 in (91 cm) at ages 7 and 11, respectively (Appendix Table A5). Growth rates of sturgeon in the lower Columbia River have declined by about 10% from 1947-1953 to 1980-1983 (Hess 1984).

Biologists have different interpretations of ages and growth rates of young white sturgeon in the Columbia River (Beamesderfer et al. 1989; Parsley et al. 1989; Beamesderfer et al. 1990a; Duke et al. 1990). The differences center on interpretation of the first five years of age and whether the white sturgeon downstream from Bonneville Dam grow at a slower rate during this period than sturgeon upstream. Evaluating the differences in these professional opinions is beyond the scope of this document.

C. COLUMBIA RIVER UP TO CHIEF JOSEPH DAM AND THE LOWER SNAKE RIVER TO LOWER GRANITE DAM

The Columbia River Basin upstream from Bonneville Dam spans seven states and one Canadian province. The river basin has been developed for hydroelectric generation, flood control, irrigation storage, and diversion projects. International treaties, domestic law, and legal agreements govern the use of the water. Development has greatly modified the seasonal patterns of flow and temperature in parts of the basin (Mullan et al. 1986).

The impoundments upstream from Bonneville Dam contain a series of isolated white sturgeon populations. In recent years, upstream and downstream movement of sturgeon has been minimal, with less than 100 sturgeon passing through the Bonneville Dam fish ladder annually (Appendix Table A2). However, at the impoundments upstream from Bonneville Dam, movement of sturgeon has been much greater.

Marked sturgeon are rarely found outside the pool where they were marked (R. Beamesderfer, ODFW, pers. commun.). Before fish locks ceased operations, small numbers of large sturgeon were moved upstream during optimal conditions (Donaldson 1958, unpublished manuscript). Only a small portion (if any) of the population uses the navigation locks to move upstream between reservoirs. Evidence of downstream passage from one reservoir to another is sparse, but a few tagged fish passed downstream (Malm 1978; Beamesderfer et al. 1990a).

If white sturgeon were originally distributed throughout the basin and presently do not move freely between impoundments, then each discrete area may support isolated populations (Figure 5). Table 1 provides a summary of the presence of white sturgeon within these isolated areas. The dams in the Columbia River were constructed over a period of about 40 years, defining the discrete areas of the river we recognize today (Appendix Table B1).

Bonneville Pool

Habitat Available

Bonneville Pool is 46 miles (74 km) long and has a surface area of 20,400 acres (8,262 ha), an area 5,000 acres (2,025 ha) greater than the original river channel. Average depth is 28 ft (8.5 m; Mullan et al. 1986), which is relatively shallow for a Columbia River reservoir. The sand bottom supports large areas of aquatic macrophytes in the summer. Water flows into the reservoir from The Dalles Dam and several tributary rivers. During most of the year, there are measurable water velocities throughout the reservoir (R. Beamesderfer, ODFW, pers. commun.).

During the springs of 1987 and 1988, the volume of water passing through Bonneville Dam was relatively constant throughout the day. In contrast, the inflow to Bonneville Pool, controlled by the operation of The Dalles Dam, varied hourly (Parsley et al. 1989). The flow patterns and velocity profiles within the Bonneville Pool change hourly. Parsley et al. (1989) suggested that flows of less than 293,000 cfs are less favorable for spawning than flows over 406,000 cfs in The Dalles Dam tailrace. The duration of high flows may also be an important component of spawning habitat (J. DeVore, WDF, pers. commun.).

Distribution, Abundance, Status, and Productivity

White sturgeon live throughout Bonneville Pool (Beamesderfer et al. 1990a). They spawn at the upstream end of the reservoir in the tailrace of The Dalles Dam (Parsley et al. 1989; Duke et al. 1990). Juvenile fish disperse downstream from the spawning area. Duke et al. (1990) reported that 81% of their catch came from the upper third of the pool. Only 3% of the juvenile fish (12-31 in; 32-78 cm) were caught in the lower third of the reservoir, close to Bonneville Dam (Duke et al. 1990). The densities of sturgeon >28 in (>71 cm) were three times greater in a small area close to The Dalles Dam than at other locations in the reservoir, but densities were similar throughout the rest of the reservoir (Beamesderfer et al. 1990a).

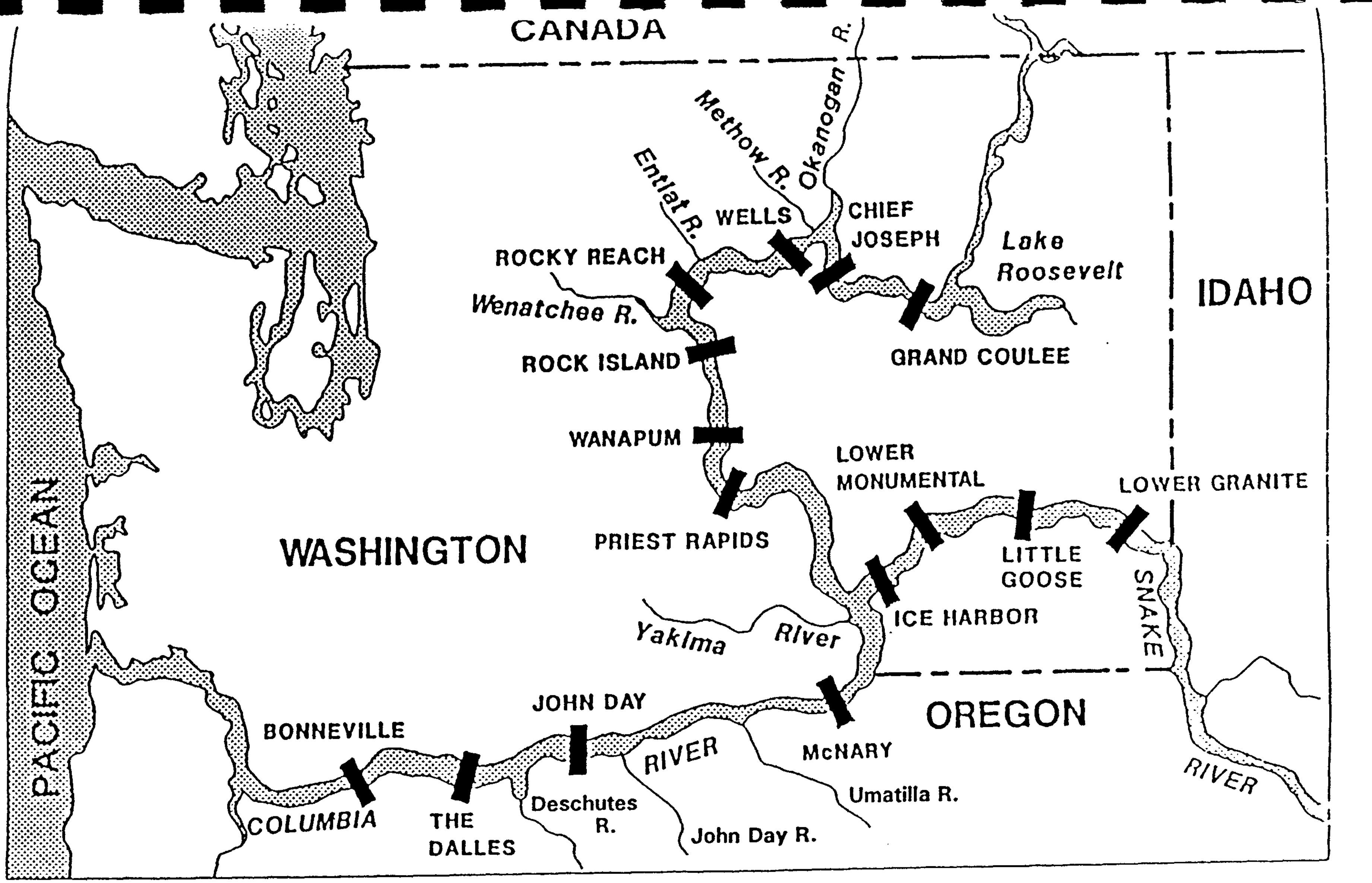

Figure 5. Map of the Columbia River upstream from Bonneville Dam and the hydroelectric projects on the mainstem Columbia and Snake rivers (adapted from Mullan et al. 1986).

Table 1. Presence of white sturgeon in the mainstem Columbia River up to Chief Joseph Dam, and in the lower Snake River to Lower Granite Dam.

Location	Presence	Source
Columbia		
Bonneville Pool	yes	Malm 1978; Beamesderfer et al. 1989
The Dalles Pool	yes	Beamesderfer et al. 1989
John Day Pool	yes	King 1985
McNary Pool	yes	DeVore et al. 1990
McNary Pool to Priest Rapids	yes	Haynes et al. 1978
Snake R. upstream to Ice Harbor	yes	DeVore et al. 1990
Yakima River (trib. to region)	yes	S. Parker, YIN, pers. commun.
Mid-Columbia		
Priest Rapids Pool	yes	Mullan et al. 1986 S. Parker, YIN, pers. commun.
Wanapum Pool	yes	WDF, unpublished data
Rock Island Pool	yes	WDF, unpublished data
Rocky Reach Pool	yes	K. Williams, WDW, pers. commun.
Wells Pool	yes	K. Williams, WDW, pers. commun.
Okanogan Lake	?	Scott and Crossman 1973
Snake River		
Ice Harbor Pool	yes	Bennett et al. 1983
Lower Monumental Pool	yes	Bennett et al. 1983
Little Goose Pool	yes	Bennett et al. 1983

Setline CPUE during sampling from 1988-1989 indicated that the density of small sturgeon (<35 in; <89 cm FL) was at least twice as high in Bonneville Pool than in The Dalles or John Day pools (R. Beamesderfer, ODFW, pers. commun.; Appendix Table B4). However, mid-sized (35-71 in; 89-180 cm FL) and large (>71 in; >180 cm FL) white sturgeon were less abundant in the Bonneville Pool than in The Dalles Pool (R. Beamesderfer, ODFW, pers. commun.; Appendix Table B4).

Malm (1978) estimated a population of 32,000 white sturgeon (12-96 in; 30-245 cm FL) in Bonneville Pool. In 1989, abundance of fish larger than 24 in (61 cm) TL was estimated to be at least 48,500 or 1,050 fish per mile (653 fish/km; ODFW, unpublished data). Percent abundance of sturgeon by TL categories of 2-3 ft (0.6-0.9 m), 3-4 ft (0.9-1.2 m), 4-6 ft (1.2-1.8 m), and >6 ft (>1.8 m) was 63%, 33%, 2%, and 1%, respectively.

Successful white sturgeon recruitment occurs in Bonneville Pool. Young-of-the-year fish were collected in 1989 (Duke et al. 1990). Although recruitment occurs, Duke et al. (1990) implied that recruitment was low from 1986-1988. The CPUE of juvenile sturgeon (13-31 in; 33-79 cm) was relatively constant between 1988 and 1989 sampling (Duke et al. 1990). Smaller sturgeon (<32 in; <81 cm FL) were also more abundant than larger sturgeon (>31 in; >80 cm), based on setline CPUE data (Beamesderfer et al. 1990a). The 1986-1988 year classes should have been included in sampling by Duke et al. (1990), but may not be represented in the <32-in (<81 cm) size class reported by Beamesderfer et al. (1990a) due to size selectivity of the setlines used for sampling.

Growth of white sturgeon in Bonneville Pool is poor relative to other lower Columbia River reservoirs and the free-flowing river downstream from Bonneville Dam. Fish in Bonneville Pool grow to 36 in (91 cm) TL in an average of 14-15 years (Malm 1978; Beamesderfer et al. 1990a).

The Dalles Pool

Habitat Available

The Dalles Pool (Lake Celilo) is about 24 miles (39 km) long, with a mean depth of 28 ft (8.5 m; Mullan et al. 1986) and a maximum depth of over 131 ft (40 m; Palmer et al. 1988). The surface area is 11,650 acres (4,718 ha) or about twice the original surface area of the river (Mullan et al. 1986). Most (80%) of the reservoir is deeper than 18 ft (5.5 m) and over 40% of the reservoir is deeper than 30 ft (9 m; Duke et al. 1990). The Deschutes River flows into the pool from the south side of the river.

During the springs of 1987 and 1988, there were large hourly variations in discharge at The Dalles Dam and inflow from John Day Dam. Hourly velocities within the pool probably vary with discharge.

The Dalles Pool is a deep riverine canyon and has more rock substrate than the adjacent Columbia River pools (R. Beamesderfer, ODFW, pers. commun.).

Distribution, Abundance, Status, and Productivity

White sturgeon occur throughout The Dalles Pool and tagged fish moved throughout the reservoir (Beamesderfer, ODFW, pers. commun.). Spawning occurs in the tailrace of the John Day Dam (Parsley et al. 1989; Duke et al. 1990). Eggs or larvae were collected in the tailrace and 11 miles (17.6 km) downstream (Duke et al. 1990). Few fish <28 in (<71 cm) long were captured in 1989 (Beamesderfer et al. 1990a). Juvenile sturgeon >28 in (>71 cm) were six times as abundant in the upstream portion of the reservoir (near John Day Dam) as they were at other locations (Beamesderfer et al. 1990a). Juveniles moved about 10 miles (16 km) upstream or not at all (Duke et al. 1990).

Numbers of white sturgeon (>24 in; 61 cm TL) in The Dalles Pool declined from minimum estimates of 30,100 fish (1,260/mi; 783/km) in 1987 to 12,000 fish (500/mi; 311/km) in 1988 with the removal of nearly 6,000 fish by sport and commercial fisheries (ODFW, unpublished data). In 1988, percentages of fish in TL categories of 2-3 ft (0.6-0.9 m), 3-4 ft (0.9-1.2 m), 4-6 ft (1.2-1.8 m), and >6 ft (>1.8 m) were 37%, 35%, 23%, and 5%, respectively.

Recruitment of white sturgeon in The Dalles Pool may be less than in Bonneville Pool (Duke et al. 1990). Setline CPUE from sampling in 1988-1990 confirms that densities of small fish (<36 in; 91 cm TL) in The Dalles Pool are less than half the densities seen in Bonneville Pool, but at least four times greater than in the John Day Pool (Beamesderfer et al. 1990a; Appendix Table B4). Densities of larger fish in The Dalles Pool exceed densities in the Bonneville and John Day pools.

Growth rates of age 1-5 fish in The Dalles Pool may exceed rates seen downstream from Bonneville Dam and in Bonneville Pool (Duke et al. 1990). This good early growth in The Dalles Pool is apparently offset by reduced growth of older fish. At a mean age of 9, sturgeon in The Dalles Pool reach an average length of 36 in (91 cm), which is comparable to growth of the population downstream from Bonneville Dam (Beamesderfer et al. 1990a).

John Day Pool

Habitat Available

This section of regulated river flows through an arid region dominated by basalt rock. The John Day and Umatilla rivers flow into the pool. John Day Pool (Lake Umatilla) is about 76 miles (122 km) long with a mean depth of 46 ft (14 m). The surface area is 51,000 acres (20,655 ha), about twice the original surface area of the river (Mullan et al. 1986).

This pool has the largest storage ratio of the Columbia River impoundments downstream from Grand Coulee Dam (Mullan et al. 1986). The John Day Pool is not exclusively a run-of-the-river project as it provides some flood control. The retention time of the reservoir is 3-12 days from May to September (LaBolle 1984).

LaBolle (1984) described macrohabitats in the reservoir with different depths and velocities. The littoral zone extends about 98 ft (30 m) from shore. *Potomogeton* grows along the deeper littoral regions, while the shallower parts of the reservoir margin support emergent plants. There are detectable water velocities throughout the reservoir (R. Beamesderfer, ODFW, pers. commun.).

Distribution, Abundance, Status, and Productivity

Juvenile sturgeon (12-38 in; 30-97 cm) are dispersed in the pool, but most are found in the upper third of the reservoir (Duke et al. 1990). Spawning occurs in the tailrace of McNary Dam as evidenced by the collection of eggs and larvae in the tailrace (Duke et al. 1990).

White sturgeon abundance in the John Day Pool is much less than in The Dalles and Bonneville pools despite John Day's larger pool size. The 1990 population was estimated at 4,200 fish (>24 in; >61 cm TL) or 60 fish/mi (37 fish/km; ODFW, unpublished data). Percentages of fish in TL categories of 2-3 ft (0.6-0.9 m), 3-4 ft (0.9-1.2 m), 4-6 ft (1.2-1.8 m), and >6 ft (>1.8 m) were 50%, 33%, 10%, and 7%, respectively. Setline CPUE from sampling in 1988-1990 confirms densities are much less than in other lower Columbia River reservoirs for all size classes.

Low densities of sturgeon in John Day Pool may reflect recent high harvest rates rather than poor habitat (ODFW and WDF, unpublished data). Sport catch rates declined from 0.023 fish per hour in 1984-1986 (Beamesderfer et al. 1990a) to <0.01 fish/hr by 1989 (DeVore et al. 1990). Current catch rates are the lowest reported in the lower Columbia River.

Poor recruitment of white sturgeon may also contribute to low sturgeon densities in John Day Pool. The average CPUE for juvenile sturgeon (13-38 in; 33-97 cm) collected during trawl sampling in John Day Pool was 0.66 fish/hr (Duke et al. 1990). This is a low CPUE for the size class. Similar gear collected 3.96 fish/hr in The Dalles Pool and 6.59 fish/hr in Bonneville Pool (Duke et al. 1990).

Sturgeon growth rates of ages less than 9 years in John Day Pool are as good or better than rates seen anywhere in the lower Columbia River, including downstream from Bonneville Dam. Fish reach 36 in (91 cm) TL at a mean age of 9 (ODFW, unpublished data).

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McNary Pool and Portions of the Snake and Columbia Rivers

McNary Pool (Lake Wallula) and riverine areas in the Columbia River downstream from Priest Rapids Dam and the Snake River downstream from Ice Harbor Dam provide some of the more diverse habitats for sturgeon upstream from Bonneville Dam. McNary Pool is 61 miles (98 km) long with a surface area of 38,800 acres (15,390 ha). The mean depth of the pool is 35 ft (11 m). The storage ratio of McNary Pool is half that of the downstream John Day Pool. The reservoir, or slack water, extends upstream beyond the confluence of the Snake River. McNary Pool extends up the Snake River five miles (8.0 km) to Ice Harbor Dam. The Snake River arm of the reservoir is usually warmer than the rest of the pool during late summer and fall. Just upstream from the confluence of the Snake River is the Hanford Reach, the longest (44 mi; 71 km) free-flowing section of the Columbia River remaining in the United States upstream from Bonneville Dam.

The only information available to describe this sturgeon population was the 1988 preliminary estimate of 421 white sturgeon that were harvested in this river reach by Washington sport anglers (Zinicola and Hoines 1988). For the Hanford Reach in 1990, the CPUE for boat anglers (legal size 48-66 in; 122-168 cm) was 0.029 fish/hr, and 0.0 fish/hr for bank anglers.

Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells Pools

The waters between Priest Rapids Dam and Chief Joseph Dam tend to be cooler than those in the Snake River, especially during the summer (Mullan et al. 1986). Cold water from Grand Coulee Dam warms slowly as it passes downstream through these small run-of-the-river projects with low retention times (Appendix Table B1). Average reservoir depths range from 24-49 ft (7-15 m).

The tailrace of each of these dams flows directly into the next reservoir downstream, instead of into riverine habitat. An exception is the Wells Pool, where several miles of river with deep pools separate the Chief Joseph Dam tailrace from the slack water of Wells Pool.

Although white sturgeon inhabit all these waters, abundance, status, and productivity data are sparse. Estimated 1988 angler harvest in Priest Rapids Pool was 34 white sturgeon (Zinicola and Hoines 1988). Harvest from Wanapum, Rock Island, and Chief Joseph pools during 1988 was no more than 10 sturgeon per pool (Zinicola and Hoines 1988). A few sturgeon were reported caught in the river upstream from the Wells Pool in 1989 (Zinicola and Hoines 1988; K. Williams, WDW, pers. commun.).

Ice Harbor, Lower Monumental, and Little Goose Pools

The Ice Harbor, Lower Monumental, and Little Goose pools form three continuous slack water regions without flowing river sections between them. Summer temperatures in these three pools of the lower Snake River may exceed 77° F (25° C).